Performance analysis of TDMA-based Wireless Network for Safety-critical Avionics

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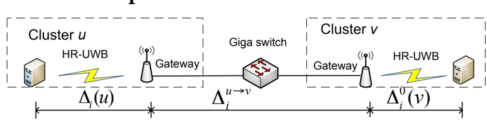
The opportunities and challenges for using wireless interconnects for safety-critical avionics have been discussed in our previous work[1].A Wireless Avionics Network (WAN) has been proposed based on hybrid architecture UWB and Switched Ethernet with adequate reliability and security mechanisms to increase scalability and reduce electromagnetic susceptibility (figure 1). Furthermore, a TDMA-based protocol was considered to guarantee a contention free access and enhance communication predictability. However, the use of wireless technologies may increase the communication latencies due to transmission errors, and real time constraints have to be verified. In order to deal with the worst case performance analysis of such network, an appropriate schedulability analysis based on Network Calculus formalism is presented in this paper and obtained results for a realistic case study are discussed herein.

Figure 1: Proposed Wireless Avionics Network



System Modeling In order to integrate the different characteristics of the traffic generated by avionics applications, three parameters (T_i, D_i, L_i) are defined for each traffic class i to denote respectively the period, the deadline and the message length that integrates the different protocol overheads. Let's consider $n_u^{(i,k)}$ the number of messages in traffic class i generated by the node k in cluster u and $p_u^{(i,k)}$ the associated packet error rate. Hence, the expected number of transmitted messages to deliver correctly $n_u^{(i,k)}$ messages is $\overline{n_{Cl_u}^{(i,k)}} = \lceil \frac{n_u^{(i,k)}}{1-p_u^{(i,k)}} \rceil$. Then, the transmitted traffic class i by node k is modeled with the affine arrival curve:

$$\alpha_u^{(i,k)}(t) = \overline{n_u^{(i,k)}}.(L_i + \frac{L_i}{T_i}) \qquad (1)$$

Each considered node k in cluster u schedules its generated messages according to Weighted Fair Queuing (WFQ) policy where each traffic class i admits an associated weight $w_u^{i,k}$ where $\sum_i w_u^{i,k} = 1$. Furthermore, each node k in cluster u can transmit its messages only during its associated time slot s_u^k where $\sum_k s_u^k = c_u$ and c_u is the TDMA cycle.

Hence, the service curve offered by the cluster u to each traffic class i transmitted by a node k is modeled as follows:

$$\beta_u^{(i,k)}(t) = B \max(\lfloor \frac{t}{c_u} \rfloor \phi_u^{i,k}, t - \lceil \frac{t}{c_u} \rceil (c_u - \phi_u^{i,k})) \qquad (2)$$

where B is the transmission capacity of the network and $\phi_u^{i,k} = s_u^k * w_u^{i,k}$ is the residual time slot of node k to transmit traffic class i.

The considered Ethernet switch admits a Store and Forward mode and FCFS scheduling strategy. This can be modeled with the service curve $\beta_{sw}(t) = \max(0, C[t - \frac{L_v}{C})$ where L_v is the maximum size of Ethernet frame encapsulating the UWB messages sent by the different gateways.

Schedulability Analysis In order to verify the schedulability of our proposal, the upper bounds on end to end delays are calculated and compared to respective deadlines. This delay consists of three parts as shown in figure 1: $\Delta_i^k(u)$ and $\Delta_i^0(v)$ that correspond to the worst case intra-cluster communication delays within clusters u and v, associated to traffic class i sent from node k and the gateway, respectively. These delays correspond to the horizontal distance between the defined arrival and service curves; $\Delta_i^{u->v}$ that corresponds to the worst case inter-cluster communication delay from cluster u to cluster v associated to traffic class i due to the switch. This delay represents the horizontal distance between the output arrival curves coming from the gateways and the switch service curve.

Traffic classes	$PER = 0\%$	$PER = 1\%$	$PER = 2\%$
TC1 (P=2ms)	9,215ms	9,227ms	9,228ms
TC2 (P=32ms)	41,650ms	44,292ms	44,333ms

Table 1: Maximal End to End delays bounds

The maximal end to end delays with different values of packet error rates obtained for a representative A380's avionics communication network are described in table 1. This WAN consists of 56 endsystems separated in three clusters with almost 200 inter-cluster flows and 400 intra-cluster flows with periods of 2ms or 32ms. We consider as a first step a fair slots allocation for the different nodes based on their generated traffic rates to implement the TDMA protocol. As it can be noticed, the deadlines of the two traffic classes are not respected with this considered configuration.

These first results show that the choice of the TDMA cycle duration and the slots allocation scheme are of utmost importance to fulfill the temporal constraints. This optimization problem will be considered in our future work to find an adequate slots allocation scheme for each cluster to minimize the end to end delays and respect the deadline constraints.

[1] *D. K. Dang, A. Mifdaoui, and T. Gayraud. "Fly-By-Wireless for next generation aircraft: Challenges and potential solutions". In IEEE Wireless Days conference, 2012*